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RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION OF THE POWER REQUIREMENTS OF SLOTTED TEST SECTIONS

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SUMMARY

A preliminary investigation of the power requirements for slotted tunnels and of methods of reducing these requirements has been conducted in a small-scale single-slot test section. All pressure losses reported were incurred in the region between the upstream end of the entrance bell and the entrance to the diffuser, and in handling air taken from the main stream through the slotted wall. The losses associated with the removal of the bleed air through the slot without recovery of the available dynamic pressure increased rapidly with Mach number and, at Mach numbers above approximately 1.0, exceeded those associated with the main flow through the tunnel. The use of a sharp-lip cutoff at the downstream end of the slot together with an auxiliary pump for bleed-air removal provided operation for Mach numbers below 1.2 at power parameters less than those for any other configuration tested.

Tests in which closed ejectors were used to pump air from the plenum indicated that the minimum required secondary nozzle area increases with Mach number, that the optimum area is the minimum area capable of generating the required Mach number, and that variations in mixing tube lengths from the optimum value effect substantial increases in power requirements.

The installation, in an open-ejector-type tunnel, of a bleed-flow passage and slot diffuser in place of the large volume plenum did not radically change the longitudinal Mach number distribution and resulted in operation at Mach numbers greater than 1.2 at power parameters less than those of any other configuration tested. It is probable that, if diffuser losses were considered, the arrangement using an auxiliary pump with properly located intake together with a sharpened cutoff at the downstream end of the slot would allow operation at less power than the ejector arrangements.

INTRODUCTION

The large power requirements of existing transonic tunnels emphasizes the need for research to reduce the energy losses across the test section. In most of these tunnels, air taken into the plenum chamber re-enters the circuit through an open ejector at the front of the diffuser; air thus enters the diffuser with a layer of low-energy air along the walls surrounding the high-energy stream.

Data obtained in tests of the Langley 8-foot transonic tunnel (ref. 1) show that the increased power over that required for comparable-sized closed tunnels is due largely to the energy losses sustained in bleeding air into the plenum surrounding the tunnel, in returning the low-energy bleed air to the main air stream at the entrance to the tunnel diffuser, and in diffusing this combined mixed flow. In some small slotted tunnels, however, the bleed air is not returned to the main stream at the tunnel diffuser but is removed from the plenum by an auxiliary pump which is operated separately from the main stream air supply. In this type of tunnel the increase in power over that required for a closed tunnel is associated with the handling of the bleed flow; the diffuser efficiency may be improved by this arrangement, however, since the bleed air may be returned to the main stream in a low velocity region and thus only minor losses incur. For either type of slotted tunnel, then, any substantial improvement in the power characteristics must be derived from improved handling of the bleed air. A preliminary investigation was therefore initiated at the Air Induction Section of the Langley Laboratory to determine the general nature of the bleed-air problem. This investigation included the determination of the power requirements of slotted test sections in which the bleed air was removed from the plenum by: (1) an auxiliary pump without return of the bleed air to the main stream, and (2) several stream-operated ejectors which act to return the bleed air to the main stream at the entrance to the tunnel diffuser. Included in the ejector tests were investigations of effects of bleed-air-jet or gap height, mixing-tube length, and slot-plenum geometry. Tests were conducted over a range of Mach numbers from 0.75 to 1.3.

SYMBOLS

A^*/A	one-dimensional area ratio required at any tunnel Mach number
a	velocity of sound, ft/sec
h'	ejector bleed-air gap height, in.

h'/h	gap ratio, also equals $\dfrac{\text{Bleed-air jet area}}{\text{Main air jet area}}$
h	tunnel height, in.
H	total pressure, lb/sq ft
l	mixing length, in.
l/h	mixing-length—tunnel-height ratio
M	Mach number, V/a
p	static pressure, lb/sq ft
T	temperature, $^{\circ}R$
V	velocity, ft/sec
w	weight flow of air, lb/sec
x	distance downstream from ejector jet exit or from slot entrance
y	distance below lower surface of floor bars, in.
hp	horsepower, 550 ft-lb/sec

Subscripts:

b	bleed air
d	main flow air, total air minus bleed air
t	total air, main stream plus bleed air
o	stagnation

APPARATUS AND METHODS

The test section used in this investigation was of constant cross-section 2.25 inches wide by 4.50 inches high and was equipped with a single rectangular slot 0.4-inch wide located in one of the 2.25-inch walls. (See fig. 1.) This single-slot test section, which has been investigated earlier (ref. 2) and shown to have a reasonably uniform

Mach number distribution, was chosen to simplify modification. The tunnel air for this investigation was supplied by a multiple-stage axial-flow compressor which is capable of supplying a pressure of 2 atmospheres.

The various arrangements of slot and ejector are presented as figure 2. For tests in which an auxiliary pump was used to remove air which had been bled through the slot, a sharp-edge slot cutoff was placed at the downstream end of the slot separating the bleed flow from the main stream flow. (See fig. 2(a).) The slot cutoff was followed by a constant-area section $4\frac{1}{2}$ inches long and a diffuser $12\frac{1}{2}$ inches in length with an area ratio of 3.11 to 1. Two slot configurations were tested with the auxiliary pumping system: (1) the rectangular slot of figure 2(a), and (2) that of figure 2(b) in which the slot diffuser was added. The initial closed ejector through which the bleed flow was returned to the main stream utilized a sharp-edge divider between the main stream and the bleed air as shown in figure 2(c). This divider, beginning at a point $10\frac{1}{4}$ inches from the leading edge of the slot, formed a constant-cross-section primary nozzle $6\frac{3}{4}$ inches long $\left(1\frac{1}{2}\,h\right)$ preceding the mixing tube which was of variable height and length, 1.222h to 1.556h and 2.67h to 13.33h, respectively. No diffuser was used in these closed ejector tests. Open ejector arrangements, so called because the main flow and bleed air are not separated by a mechanical divider as in the initial ejector, were also investigated (figs. 2(d) to 2(g)). For these open-ejector tests, the floor bars were beveled along a diagonal beginning from the lower inside edge, $9\frac{1}{2}$ inches from the leading edge of the slot, and extending to the upper outside edge at the downstream end of the slot. The angle of the bevel was fixed to pass through the upper inside edge and lower outside edge of the bars in a length of 2 inches and to pass through the upper outside edge of the bar in a length of 4 inches (at the end of the slot). The plenum scoop was of a reflexed type similar to that found to give best results in the tests of references 1 and 3. (See fig. 2(d).) Modifications to the slots used with this open ejector are presented in figures 2(e), 2(f), and 2(g); these modifications incorporate a diffuser fairing from slot to plenum (as in fig. 2(b)), a ducted bleed passage using a filler block in the plenum, and a combination of slot diffuser fairing with a ducted bleed passage, respectively. These open ejectors had a $3\frac{1}{2}$ inch (0.778h) mixing tube followed by a 2.97 to 1 area ratio diffuser.

Pressure-tube instrumentation consisted of a row of surface static-pressure tubes the entire length of the upper tunnel wall, a row of surface static-pressure-tubes on the lower wall of the ejector mixing tube, four surface static-pressure tubes in the tunnel throat, a total-pressure tube in the upstream duct, and a movable rake of eleven total-pressure and two static-pressure tubes. The plane of the rake is shown for the individual configurations in figure 2. All pressure tubes were connected to a multiple-tube manometer and the pressures were recorded photographically. Total air flow was computed by use of the throat statics and the upstream total pressure together with the stagnation temperature. Total pressures from the rake were flow-weighted and -integrated to find the total-pressure loss and then converted to a test-section power parameter which is derived in the appendix. The power requirements reported here are those required to overcome the losses occurring across the slotted test section and mixing tube between the entrance bell and the total-pressure measuring station. For all tests where the auxiliary pump was used, bleed-air—flow quantity was measured with a calibrated 2-inch-diameter orifice in the pump-intake duct; bleed total-pressure losses $\left(H_o - p_b\right)$ and main stream losses were converted separately to the power parameter derived in the appendix. For these tests with auxiliary pumping, an additional total-pressure survey not used for power calculations was conducted vertically in the region through the slot and below the floor bars on either side of the slot (figs. 2(a) and 3).

RESULTS AND DISCUSSION

Auxiliary Pumping

Rate of flow through slot.- The ratio of bleed air to total air required to produce a desired Mach number with auxiliary pumping is shown in figure 4. At Mach numbers below 0.83, no auxiliary pumping was required and all air was exhausted through the diffuser. Above $M = 0.83$, however, it became necessary to remove air from the plenum chamber, though auxiliary pumps, at a rate considerably in excess of that corresponding to isentropic expansion of the air stream to the desired Mach number. A part of this difference results from neglecting the boundary layer in the slotted region. At Mach numbers near unity, where the difference between measured and calculated bleed-flow rates is greatest, additional quantities of bleed air must be removed equal to the difference in mass between the main flow and the flow corresponding to choking in the constant-area duct following the slotted test section. Above $M = 1.2$, the rise in bleed flow is associated primarily with one-dimensional area effects and closely follows the trend of the theoretical curve. Higher flow rates were required with the slot diffuser at all Mach numbers except those between 0.98 and 1.07.

Total-pressure distribution in the slot.- In order to understand the nature of the flow in the slot and plenum better and to define the condition of the secondary flow for the ejector arrangements, a limited total-pressure survey was conducted at the bleed-flow survey-rake plane, which is located $11\frac{1}{2}$ inches from the leading edge of slot and extended from 0.1 inch above to 1.65 inches below the floor bars (fig. 2(a)). Figure 5 presents the total-pressure contours through the slot and in the bleed-air plenum for the basic auxiliary pump configuration (fig. 2(a)) at several Mach numbers. These contours show that considerable total pressure exists in the flow directly beneath the slot; however, the pressure drops rapidly in the region beneath the solid portions of the floor and approaches the tunnel static pressure. It should be noted that the flow values of total pressure indicated at the upper surface of the floor for subsonic Mach numbers is the result of mixing of the low-energy air in the slot with the main flow. At Mach numbers greater than 0.83, where auxiliary pumping is required, higher energy air is drawn into the slots and the mean total pressure rises rapidly with Mach number. These data are presented in greater detail in figure 6 where total pressure is plotted as a function of distance from the lower surface of the bars.

Power requirements.- The theoretical power requirements for a slotted tunnel test section have been calculated, by the method outlined in the appendix, on the basis of a normal-shock total-pressure loss at the free-stream Mach number together with an assumed complete loss of dynamic pressure for the bleed air which, for theoretical purposes, flows at a rate determined by the relationship between the one-dimensional stream tube area and the Mach number and is pumped by a 100-percent-efficient bleed-air pump. The experimental power requirements can be determined similarly from total-pressure surveys in the main stream and measured bleed-flow quantities with assumed total loss of dynamic pressure for the bleed flow. Theoretical and experimental power requirements for the test-section configuration shown in figure 2(a) are compared in figure 7(a). These data indicate a minimum total power requirement per pound of flow at $M \approx 0.9$. At Mach numbers above 0.9, the measured power is somewhat greater than the theoretical power primarily because of the larger required quantities of bleed air. At lower speeds, however, the losses are accountable to mixing in the slot itself. An examination of the power required by the bleed flow alone as compared to total power requirements stresses the need for keeping the bleed-air flow rate to the minimum value for generating a required Mach number and for recovering all possible total pressure in the bleed air. The bleed-flow quantity could be reduced, especially between $M \approx 0.83$ and $M = 1.2$, by reducing the length of the constant-area tube downstream of the slot and thus avoiding the choking that occurs in this Mach number range.

In an effort to recover more of the bleed-air total pressure, the sides of the slot were faired from the lower edges of the floor bars smoothly downward on an arbitrary radius to the full width of the plenum forming a bleed-air or slot diffuser. (See fig. 2(b).) The power requirements for this arrangement are presented in figure 7(b). A comparison of these data with figure 7(a) indicates a net increase in required power for the arrangement by using the slot diffuser. This increase comes entirely from the bleed air, which was handled in even larger quantities than in the original arrangement.

These tests with a sharp cutoff at the end of the slot and with auxiliary pumping for the bleed air indicate that this system can operate at powers approaching the theoretical at Mach numbers above 1.2 and that a slot diffuser is detrimental to the power characteristics of the tunnel. It appears that a reduction in power would result if the auxiliary pump intake were alined with the slot flow to take advantage of the high total pressure in the plenum at the end of the slots; any examination of the power requirements for a complete tunnel circuit should include considerations of the velocity distributions present at the entrance to the diffuser, which were excellent for these tests using the auxiliary pump, and possible savings in diffuser power gained therefrom.

Ejector Pumping

The arrangement shown in figure 2(c) has been chosen as a simple ejector for this preliminary investigation. Here h and h' are the heights of the high-velocity and low-pressure (main-stream and bleed-air) jets, respectively, and l is the length of the mixing region. Since the width is constant throughout, the gap ratio h'/h is equal to the area ratio of the secondary to primary jets. The slotted test section is followed by a constant-area tube similar to that used for the auxiliary pump configuration except for an increase in length, $1\frac{1}{2}$ h as compared to 1 h.

Effect of mixing-tube length.- Several preliminary runs established that at a gap ratio of 0.389 the tunnel could be operated up to M = 1.2. With this gap ratio of 0.389, a series of five mixing sections in 1-foot increments from 1-foot to 5-feet long and of constant longitudinal cross section were tested to determine the effect of mixing-tube length on the power required to overcome losses in the slotted test section and in the mixing tubes. Results of these tests, presented in figure 8, show a variation of almost 2 to 1 in power requirements as the mixing-tube length varied between $\frac{l}{h} = 13.33$ and $\frac{l}{h} = 2.67$ for the Mach number range tested. It is interesting to note that all lengths had a practically linear variation of power with Mach number through the test range and that all lengths required a great deal more power than the theoretical. This increase in power is due in part to the longer constant-area tube following the slotted test section and the corresponding increase in choking effects with higher required bleed flow. This choking fixes the Mach number of the main air jet and tends to fix the static pressure; thus, the performance of the ejector is penalized since increases in test section Mach number do not change the conditions of the primary ejector jet.

These data are cross-plotted by presenting power as a function of mixing length-test section height ratio for several Mach numbers in figure 8(b). Here the optimum value of $\frac{l}{h}$ appears to be about 6.4. For shorter than optimum lengths the low-energy bleed air is exhausted to atmospheric pressure without benefit of complete mixing and energy transfer from the main stream. Some improvement in mixing rate might be accomplished in the shorter sections by use of vortex generators or slats for deflecting the main air stream down into the re-entering bleed air; consequently, it may be possible to shift the point of optimum operation to a somewhat shorter section by use of these devices. As the mixing length is increased beyond the optimum value, the power parameter increased rapidly. For the longest mixing tube, $\frac{l}{h} = 13.33$, a study of the longitudinal static-pressure distribution indicated a re-acceleration toward the end of the tube. (See fig. 9.) This effect is probably due to the development of a very thick boundary layer and formation of an effective contraction in this region. The high peak pressure indicated at station $x = -3$ is the result of bleed air impinging on the lower surface of the passage which forms the bleed-air jet of the ejector. These closed-ejector data indicate a definite optimum value of mixing length which varies little with Mach number through the range tested. It is not suggested that the same length will be optimum for other ejector gaps.

Effect of gap ratio.- In addition to the initial gap ratio of 0.389, two additional gap ratios were tested to determine the effect of gap width on power requirements. The gap ratios chosen were 0.222 and 0.556; and the $\frac{l}{h} = 8$ mixing tube was used. Results of these tests are presented in figure 10. With the smaller gap, the bleed flow appeared to be limited so that the maximum attainable Mach number was reduced below that for the 0.389 gap ratio; however, increasing the gap ratio beyond 0.389 had no effect on the maximum attainable Mach number. These data also show a variation of about 2 to 1 between the power required by the two extreme cases, $\frac{h'}{h} = 0.222$ and 0.556, for the range of gap ratios and Mach numbers tested. Within its Mach number range, the configuration with the smallest gap ratio, 0.222, required the least power. The larger gap ratio caused considerable increases in power parameter because of a decrease in the efficiency of diffusion and ejector pumping. It appears, therefore, that the smallest gap capable of bleeding off the amount of air necessary to produce a desired Mach number will also be the one requiring the least power at that Mach number.

Effect of continuous open slot.- In a further attempt to recover some of the total-head energy of the bleed air, open-type ejectors were tested (figs. 2(d) to 2(g)). Here, instead of using a sharpened scoop at the end of the slot, the floor bars were tapered at the trailing edge from center to edge and from bottom to top so that the slot was completely opened at the back and allowed the bleed air to flow back into the main stream from a slot the full width of the test section. In the interests of simplicity of construction, the tapered portion of the bar was straight rather than curved or faired from the surfaces of the bar. Air from the plenum is collected by an elongated scoop similar to that presently used in several large tunnel installations (refs. 1 and 3), and brought out of the chamber through a gap 1-inch high $\left(\frac{h'}{h} = 0.222\right)$ at which point it remixes with the main flow. The leading edge of the plenum scoop is located 2 inches below the surface of the floor bars. The scoop thus functions as a collector for bleed air and as a duct to return the bleed air to the main flow; the purpose of this arrangement is to reduce mixing losses between bleed air from the slot and dormant air in the plenum.

Results of tests in which this ejector arrangement was used are presented as figure 11. The first test of this series used only the basic plenum scoop shown in the sketch (fig. 2(d)). These data, shown with circle symbols, exhibited a rise in power at Mach numbers slightly below 1.0 similar to that for the slot scoop using the auxiliary pump. (See fig. 7.) This rise might not occur at such a low Mach number if a different position of the plenum scoop lip had been investigated. An examination of the total-pressure distributions at the entrance to the diffuser indicated that this increase in required power from $M \approx 0.83$ to 0.95 is associated with the beginning of pumping by the ejector. These data show slightly higher power required than that for the most efficient closed ejector tested $\left(\frac{h'}{h} = 0.222 \text{ and } \frac{l}{h} = 8\right)$; this increase in power is attributed to an insufficient length of mixing tube on the open ejector. Higher Mach numbers were obtained with the open ejector than with the closed ejector because of the incorporation of a diffuser on the open-ejector arrangement.

Since the open ejector operated at power requirements approaching those of the closed ejector with the same gap ratio, and since it is similar to several large tunnels presently in operation, it was considered desirable to use it as a basis for several modifications designed to reduce power requirements through improved handling of the bleed-air flow. The first modification was the use of the slot diffuser which had been used with the auxiliary-pump configuration. The downstream end of this diffuser was flared to match the widening downstream end of the slot. (See fig. 2(e).) As can be seen from figure 11, the net result was an increase in required power much the same as was observed in the case of the sharpened scoop with slot diffuser.

Effect of plenum chamber size.- Another modification of the open ejector consisted of a filler block which effectively formed a plenum bleed-flow passage and ducted the bleed flow onto the scoop as shown in figure 2(f). The use of this arrangement greatly reduced the volume of the plenum, but only slight changes were observed in the longitudinal static-pressure distribution (fig. 12). The only change was an earlier rise in pressure corresponding to a shock and deceleration near the downstream end of the test section. As can be seen in figure 11, the installation of this filler produced substantial reductions in power required at subsonic Mach numbers but made little or no change from the basic open ejector configuration at Mach numbers greater than 1.0. A modification of the ducted bleed-flow passage added the slot diffuser as shown in figure 2(g) and resulted in substantial reductions of power over the entire test Mach number range. For this configuration all the energy of the bleed flow is not reduced to the level of the static pressure in the chamber, as indicated by the experimental power values falling below the theoretical values at the higher Mach numbers. Here again, the volume of the chamber is greatly reduced from that of the original tests, but changes in the longitudinal static pressure were limited to the earlier rise in pressure near the downstream end of the test section as shown in figure 12. It is noted that at Mach numbers greater than 1.2, this arrangement required less power than either of the arrangements using auxiliary pumping; however, it is probable that similar improvements in power required could be made with either of these arrangements by using the combination ducted bleed flow and slot diffuser modification if, in the case of the auxiliary pump, the point of removal of bleed air is moved to the end of the tunnel and alined with the ducted bleed-flow passage.

CONCLUSIONS

These data obtained from tests in a $2\frac{1}{4}$- by $4\frac{1}{2}$-inch constant-cross-section, single-slot test section allow the formulation of these conclusions:

(1) The use of a sharpened slot cutoff at the downstream end of the slot together with an auxiliary pump for bleed-air removal provided operation for Mach numbers less than 1.2 at power parameters less than those for any other configuration tested. If diffuser losses were considered, this might well be the most desirable arrangement from the power viewpoint, since it provides a nearly boundary-layer-free flow into the diffuser entrance.

(2) The installation in the open-ejector-type tunnel of a bleed-flow passage (small volume plenum for directing bleed flow) together with a slot diffuser did not radically change the longitudinal Mach number distribution of the basic slotted test section and resulted in operation at Mach numbers greater than 1.2 at power parameters less than those for any other configuration tested.

(3) For minimum power required in an ejector-type tunnel, there exists a definite optimum length of mixing region for a given gap ratio.

(4) For the ejector-type tunnel, the smallest gap capable of bleeding off the amount of air necessary to generate a desired Mach number will also be the one requiring the least power at that Mach number.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 25, 1953.

APPENDIX

Derivation of Power Parameter

For an isolated portion of a tunnel system such as is under consideration in the present report, certain assumptions are required. First, the tunnel diffuser is assumed to be perfect; that is, the final static pressure is equal to the initial diffuser total pressure and the final diffuser velocity is zero. Second, it is assumed that no heat transfer occurs through the tunnel walls or that the stagnation temperature of the flow is constant. The losses in such a system appear as reductions in the total pressure of the flow. Then, from any book on thermodynamics, the work required to increase the pressure of the air flowing out of the diffuser by an amount equivalent to the total-pressure drop in the tunnel is (in an isothermal process),

$$\text{Work} = wRT_o \log_e \left(\frac{H_{O_1}}{H_{O_2}}\right)$$

where work is the work in foot pounds per second, w is the weight flow per second, R is the gas constant 53.3, T_o is the stagnation temperature of the flow, H_{O_1} is the initial stagnation pressure of the flow, and H_{O_2} is the final stagnation pressure.

The power required, which is the time rate of energy required, is then, in terms of horsepower

$$hp = \frac{wT_o}{550} R \log_e \left(\frac{H_{O_1}}{H_{O_2}}\right)$$

or

$$\frac{hp}{wT_o} = \frac{R}{550} \log_e \left(\frac{H_{O_1}}{H_{O_2}}\right)$$

In order to convert the foregoing parameter to horsepower per square foot of tunnel cross-sectional area, multiply by the weight flow per square foot of tunnel area and by the stagnation temperature. The general multiplying factor $\frac{\rho V}{\rho_o a_o} \frac{p_o}{RT_o} \sqrt{\gamma g R T_o}\, T_o$ reduces to $0.92 \frac{\rho V}{\rho_o a_o} p_o \sqrt{T_o}$. It is assumed that $\rho V/\rho_o a_o$ is measured at the throat since total flow is desired and any other station is liable to errors due to slot flow. Thus, for subsonic Mach numbers, the value of $\rho V/\rho_o a_o$ corresponding to the throat Mach number must be used but, for supersonic Mach numbers, the throat is always sonic and the factor becomes $0.532 \; p_o\sqrt{T_o}$.

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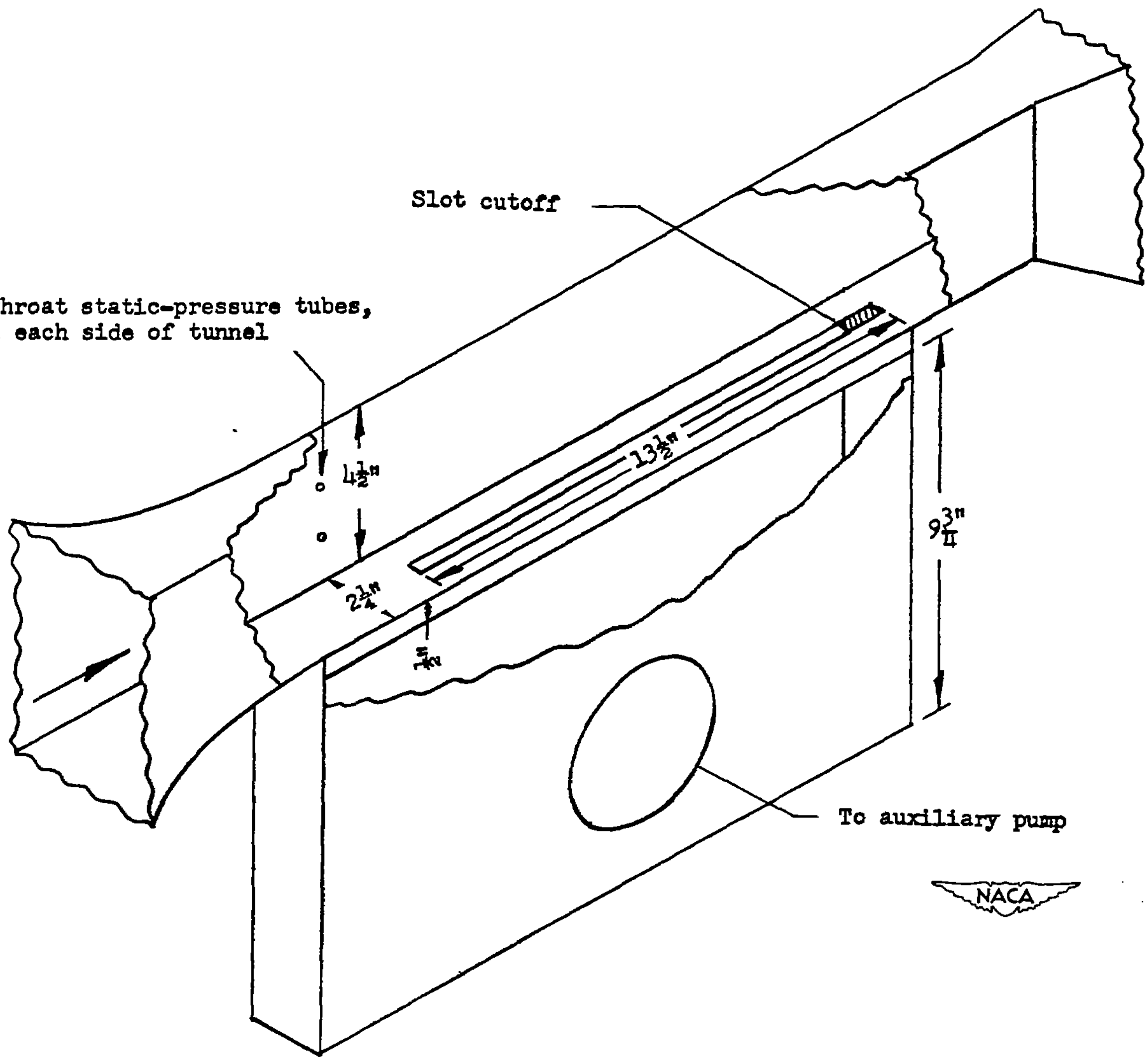
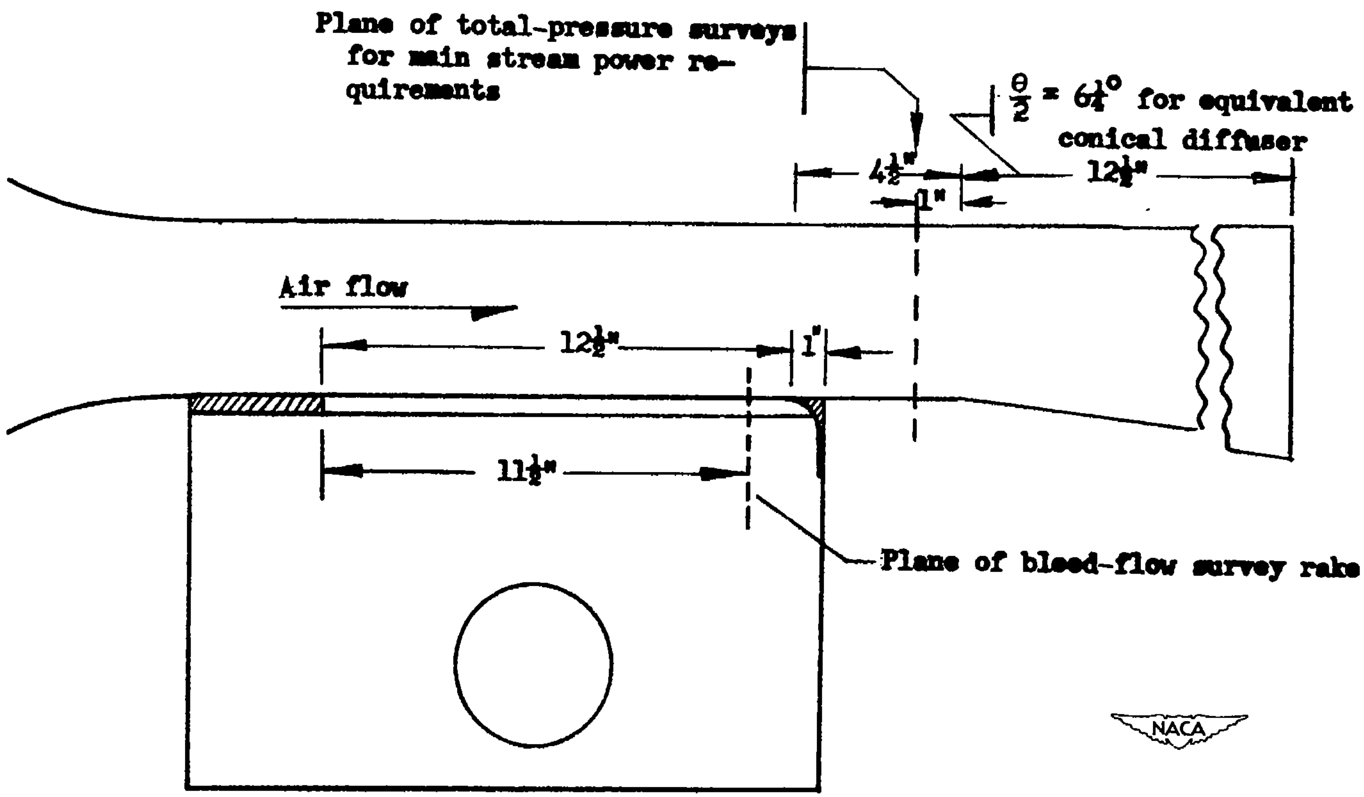
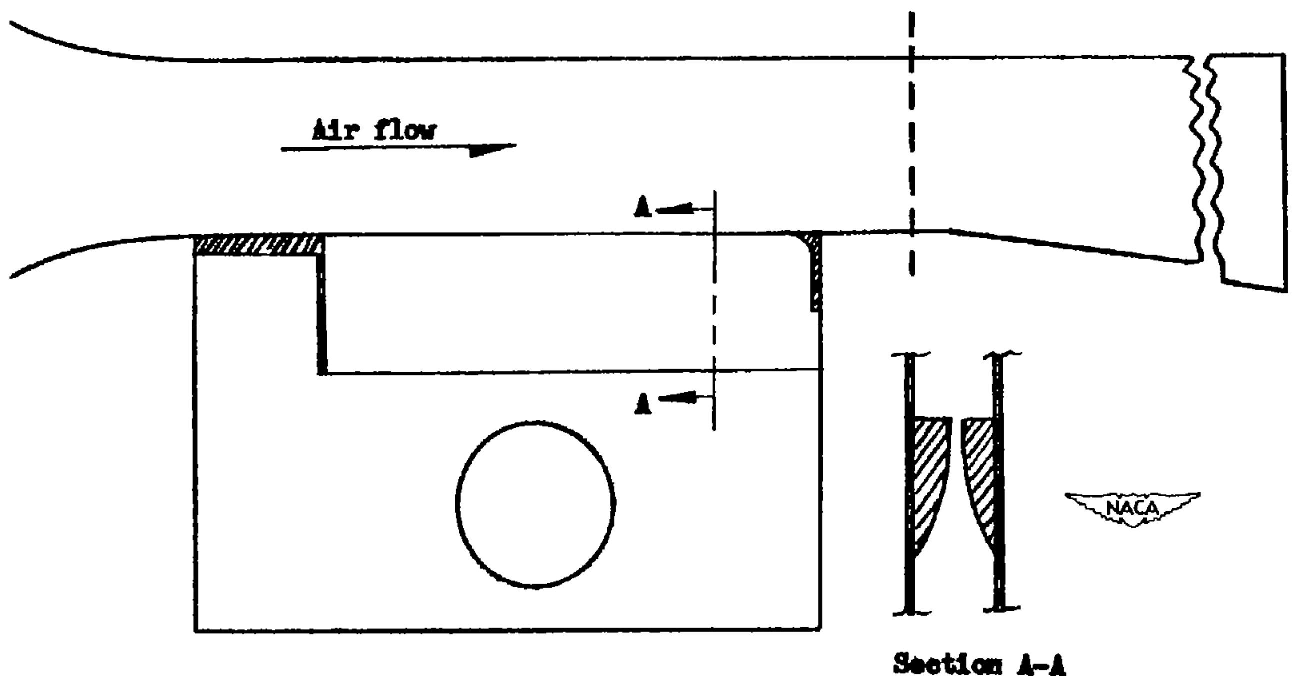


Figure 1.- General arrangement of tunnel with slot cutoff installed.



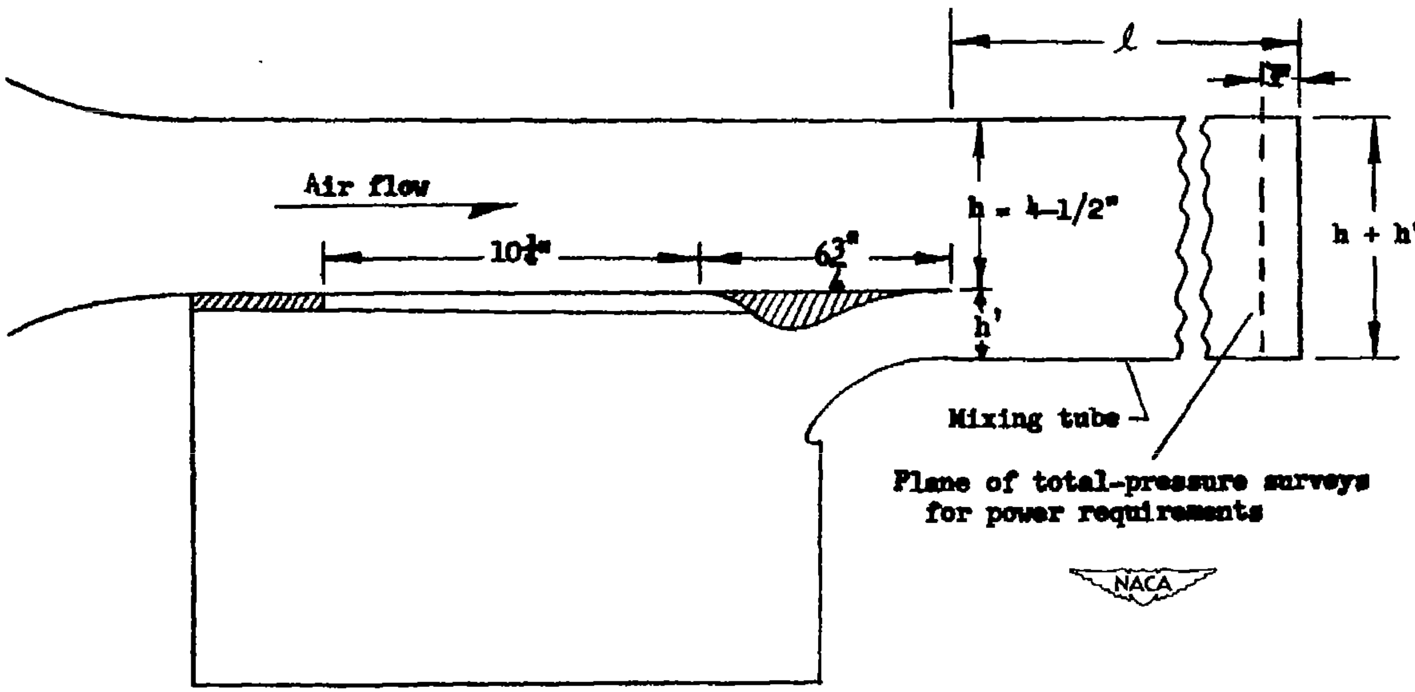
(a) Sharpened slot cutoff.

Figure 2.- Line drawings of a vertical section through the center line of the tunnel showing the various slot arrangements.



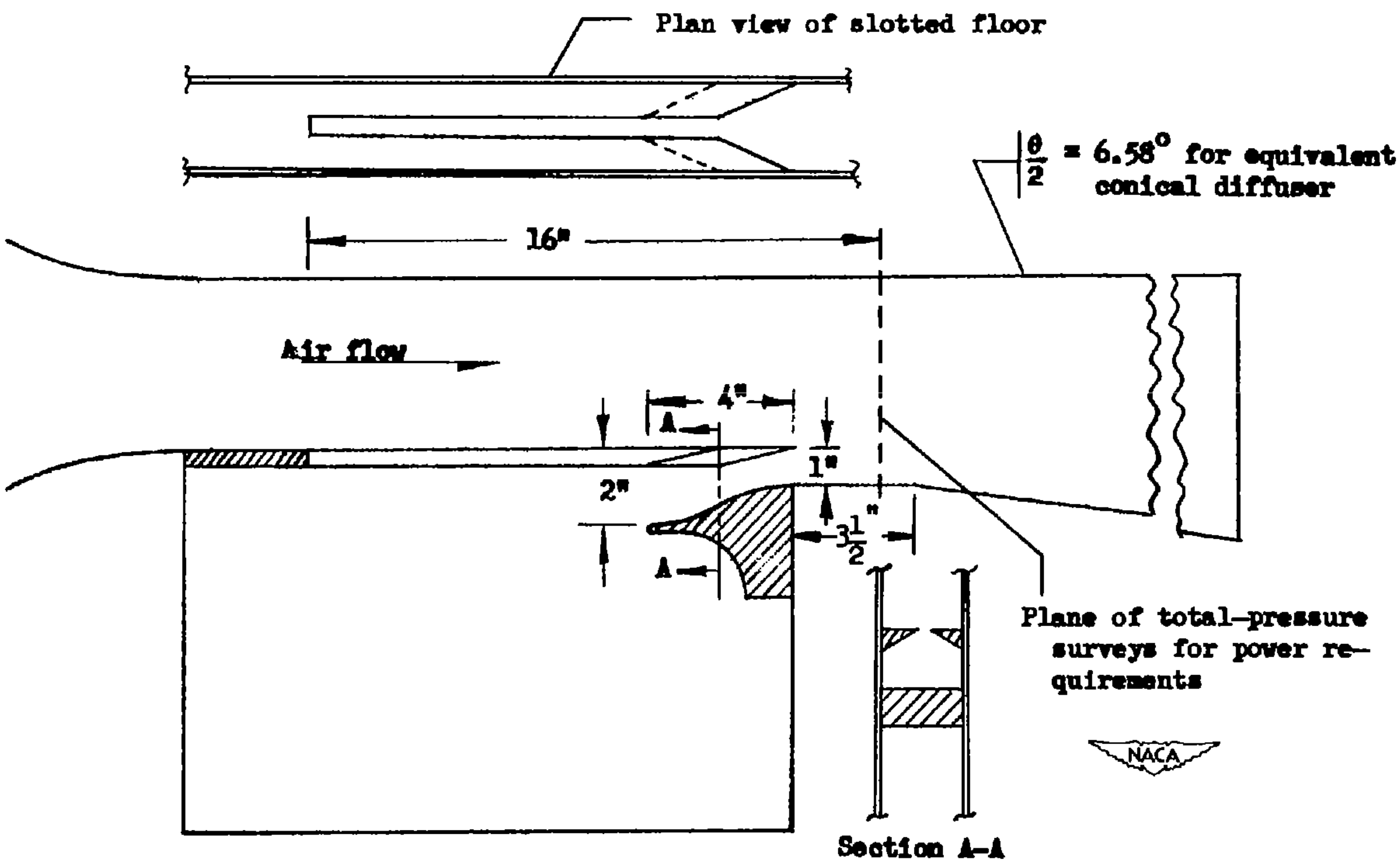
(b) Sharpened slot cutoff with slot diffuser.

Figure 2.- Continued.



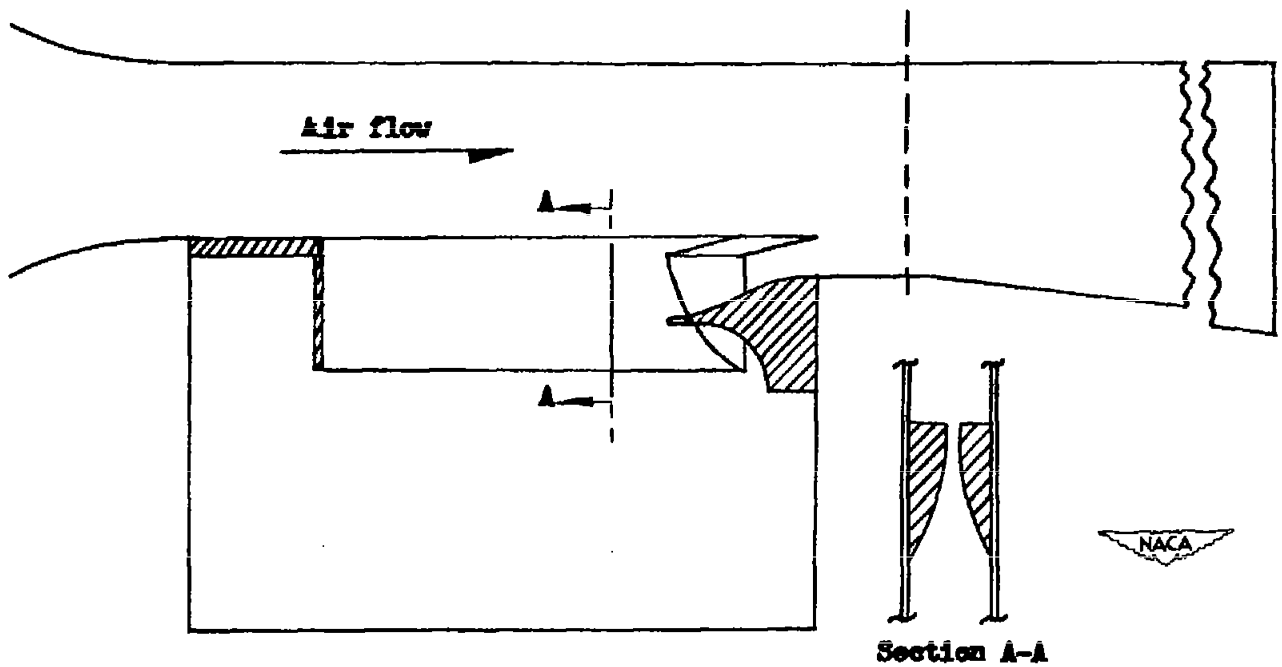
(c) Closed ejector and mixing tube.

Figure 2.- Continued.



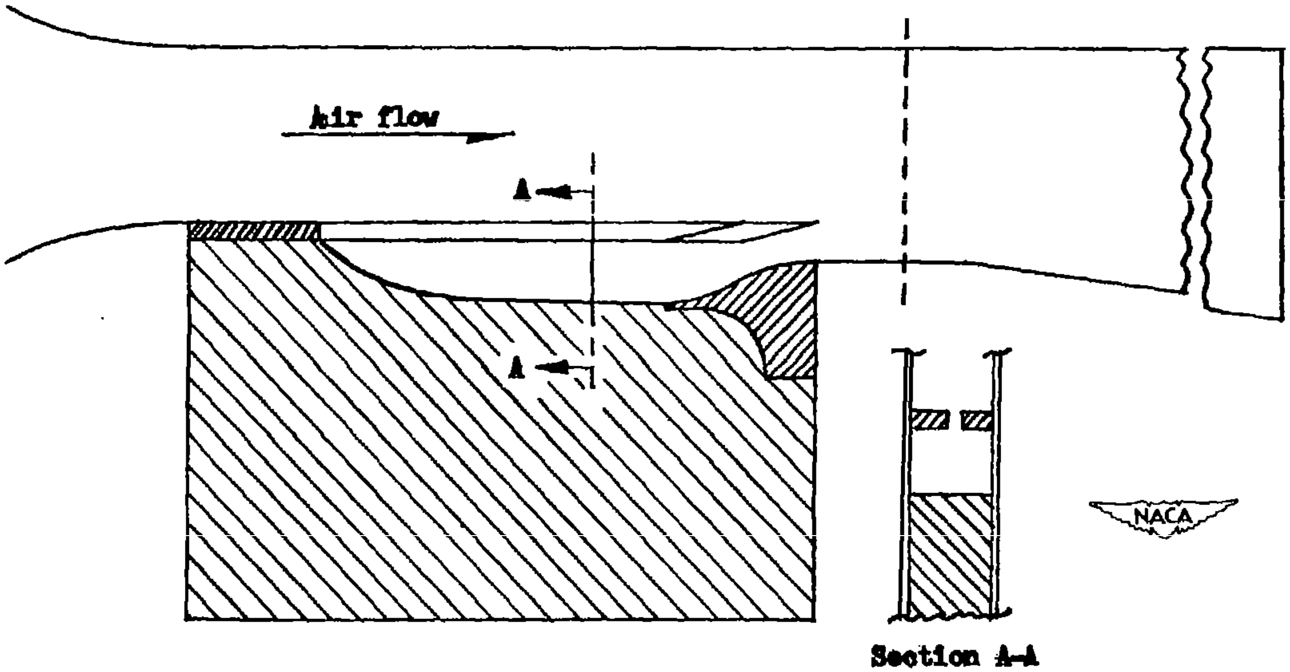
(d) Basic open ejector.

Figure 2.- Continued.



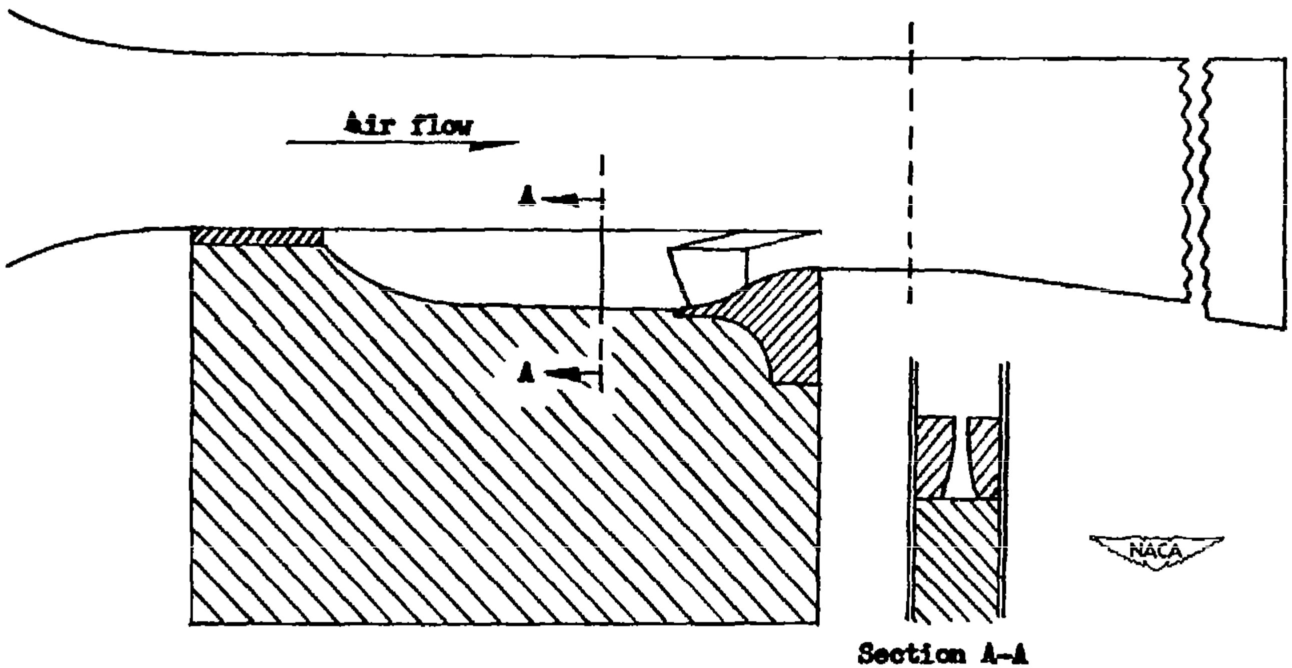
(e) Open ejector with slot diffuser.

Figure 2.- Continued.



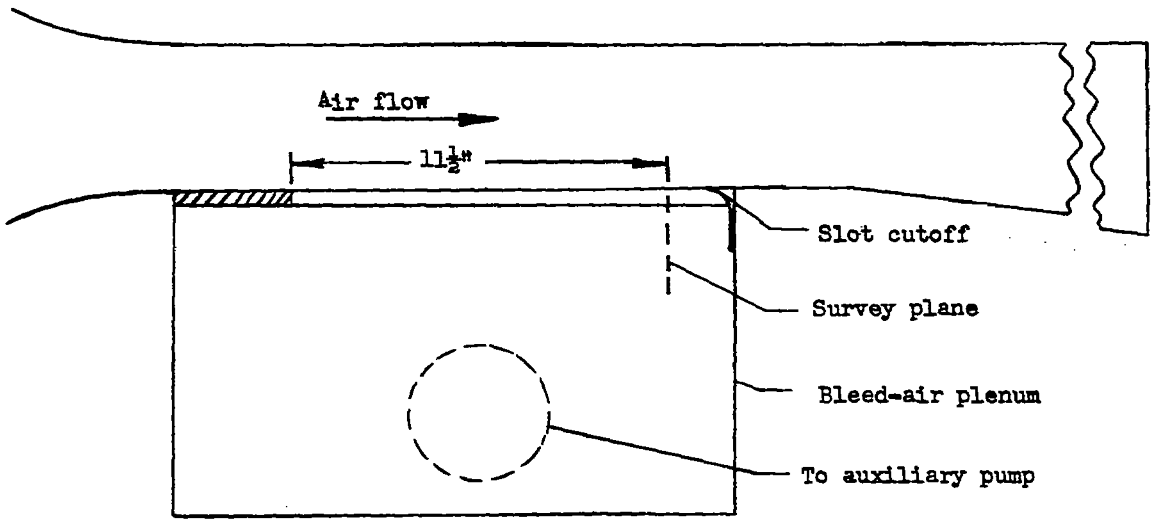
(f) Open ejector with filler block.

Figure 2.- Continued.



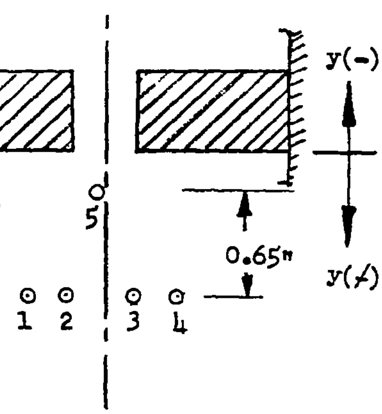
(g) Open ejector with slot diffuser and filler block.

Figure 2.- Concluded.



(a) Elevation view, section through tunnel center line.

Tube	Distance from center line, in.
1	0.48
2	.25
3	.18
4	.43
5	.06



(b) Cross section of tunnel floor at plane of rake, looking upstream.

Figure 3.- Line drawing of the location and arrangement of bleed-flow survey rake. (Used with auxiliary pump, fig. 2(a).)

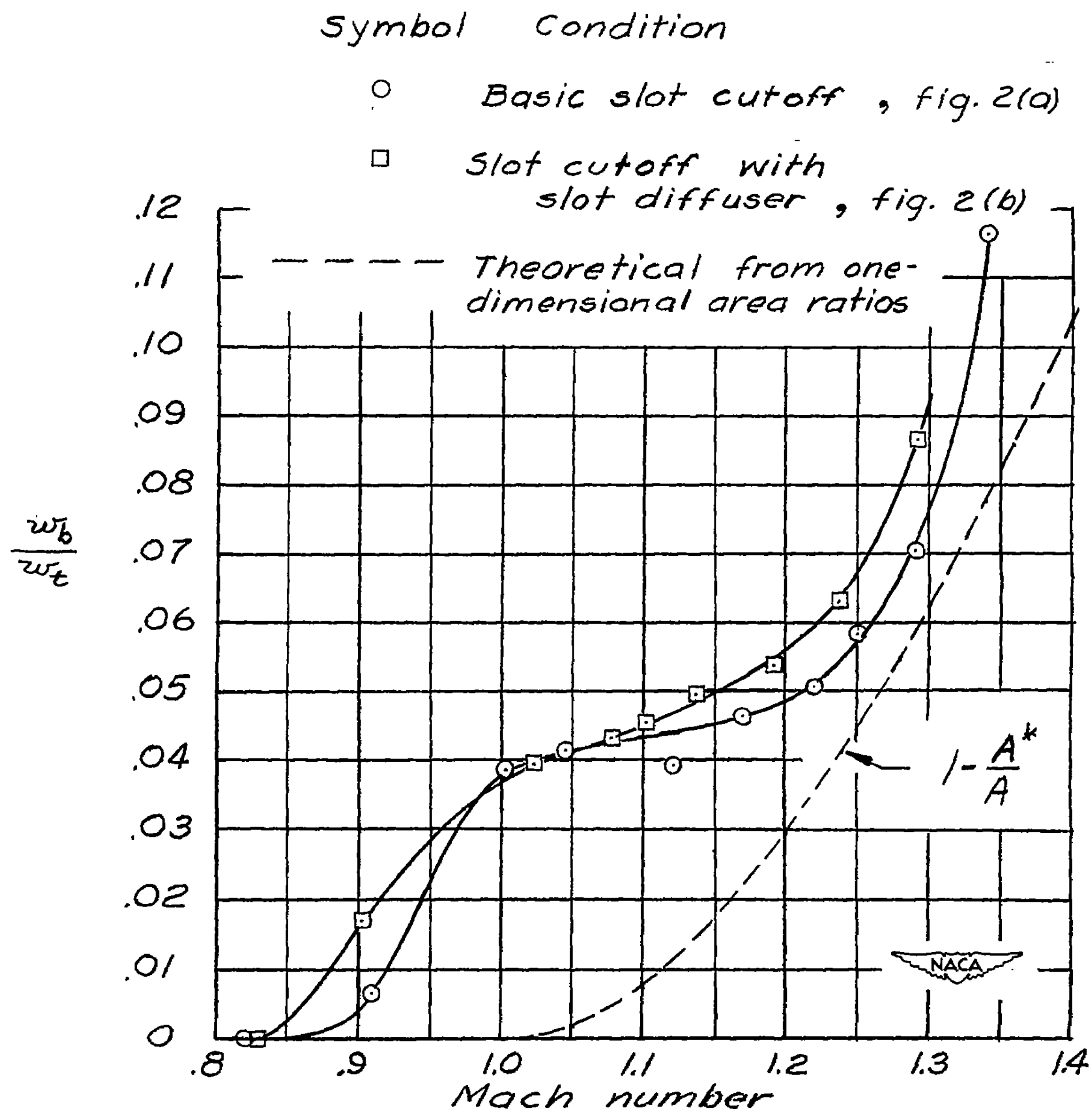
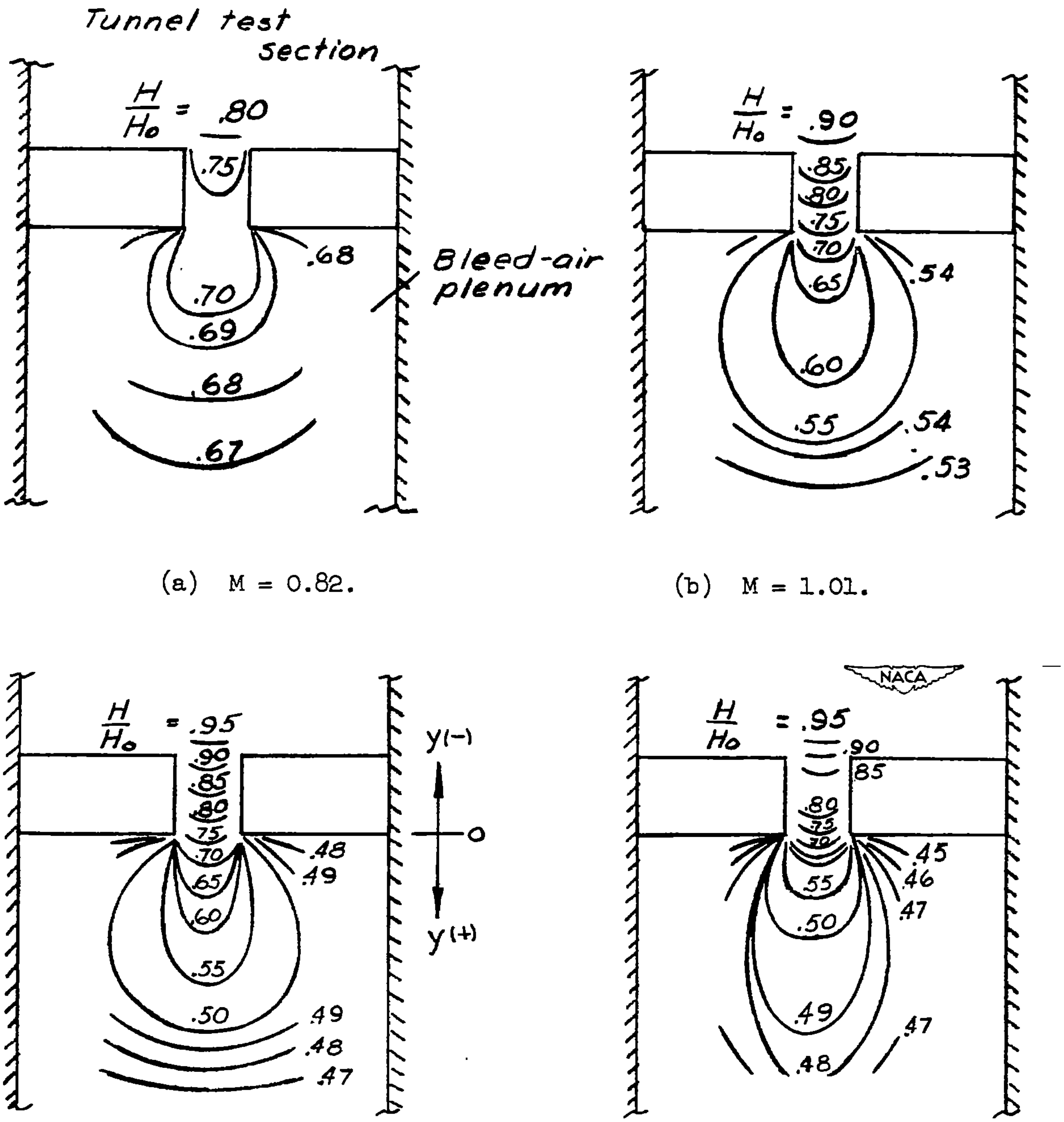


Figure 4.- Variation of rate of bleed-flow removal with Mach number for arrangements using auxiliary pumping.



(a) M = 0.82.

(b) M = 1.01.

(c) M = 1.12.

(d) M = 1.22.

Figure 5.- Contours of constant total pressure as measured with bleed-flow survey rake. See fig. 2(a).

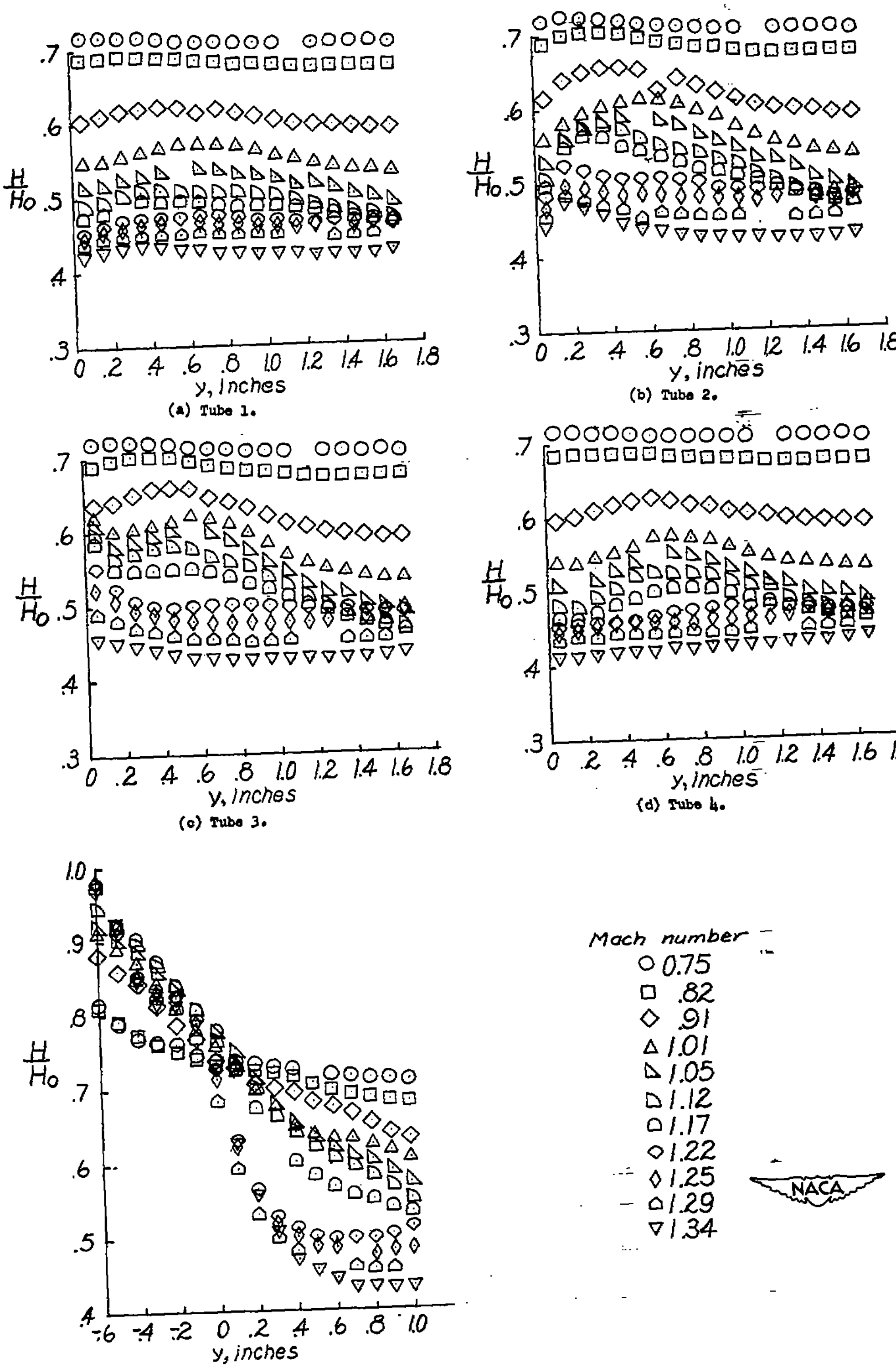
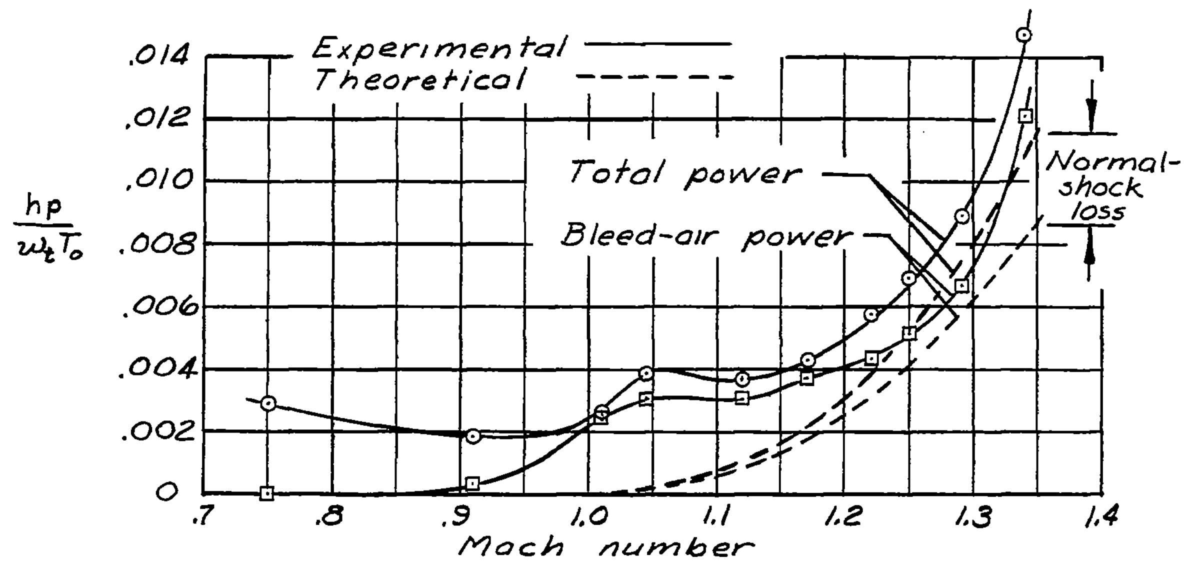
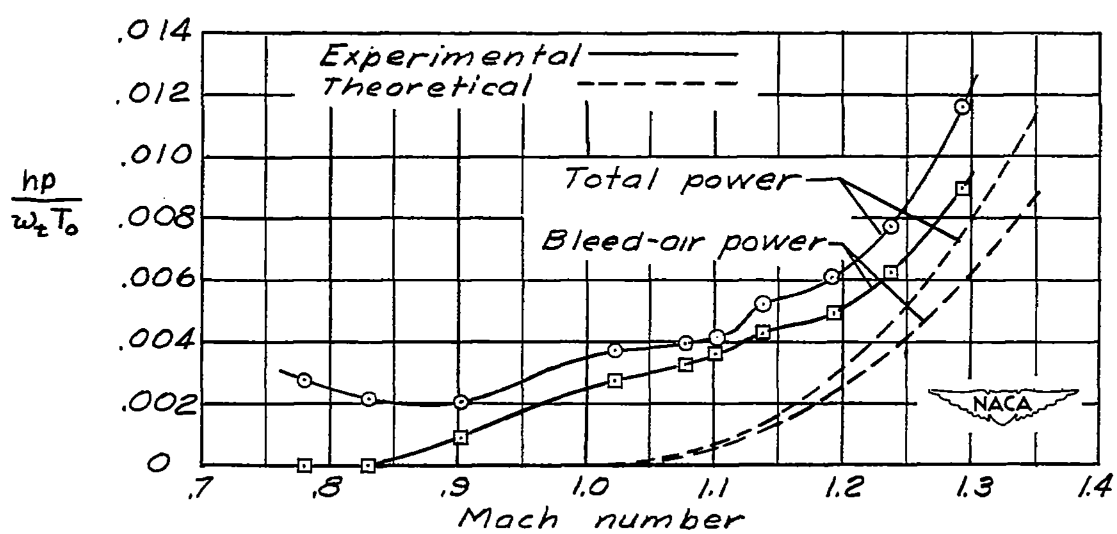


Figure 6.- Total-pressure profiles beneath slot and floor bars as measured with bleed-flow survey rake.

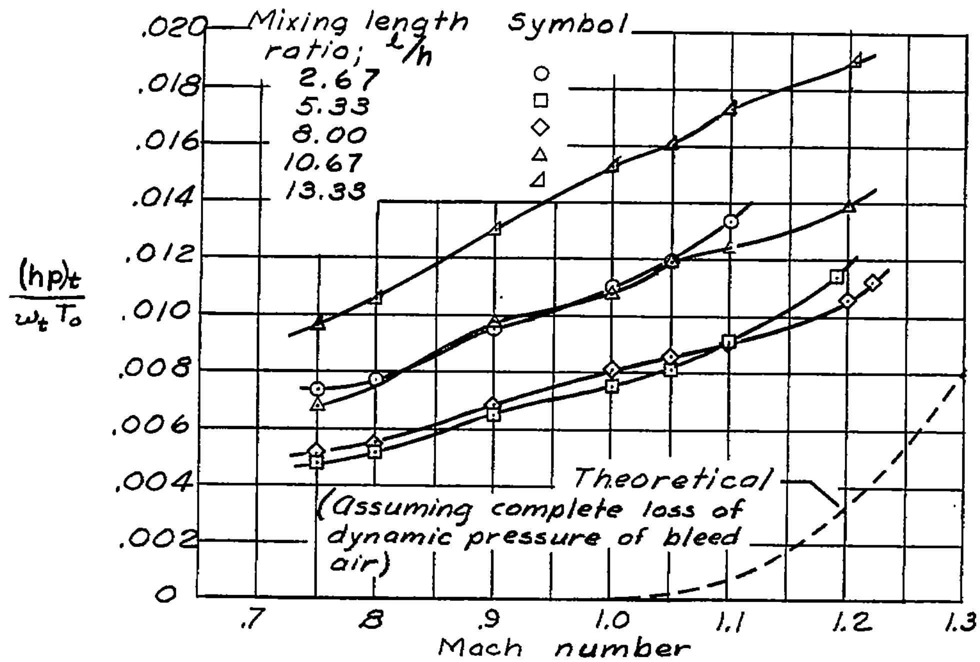


(a) Basic slotted floors. See fig. 2(a).

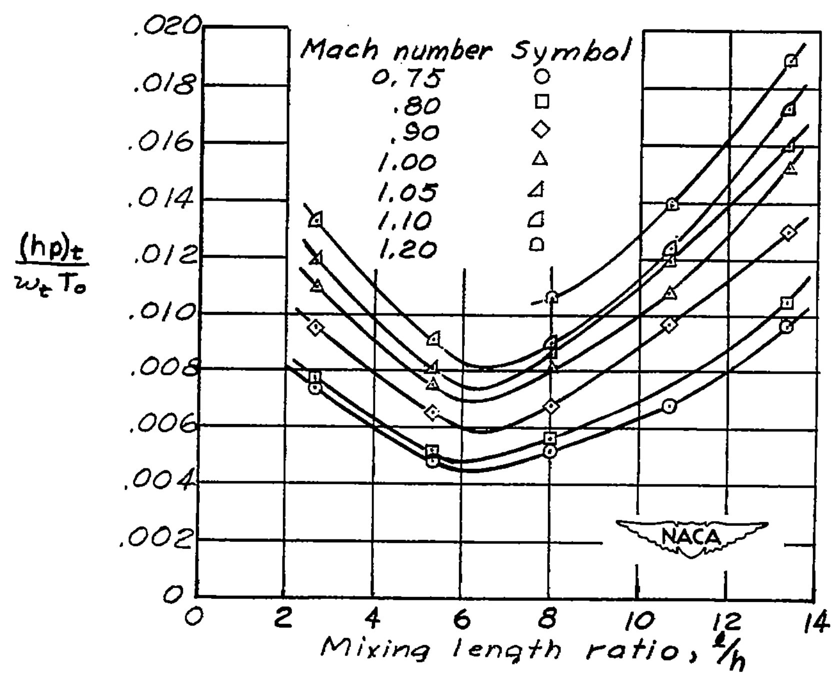


(b) With slot diffuser. See fig. 2(b).

Figure 7.- Variation of power required with Mach number for slot cutoff arrangements using auxiliary pumping for bleed air.



(a) Mixing-length ratio constant.



(b) Mach number constant.

Figure 8.- Variation of power with ejector mixing-length ratio for several values of Mach number $\frac{h'}{h} = 0.389$. See fig. 2(c).

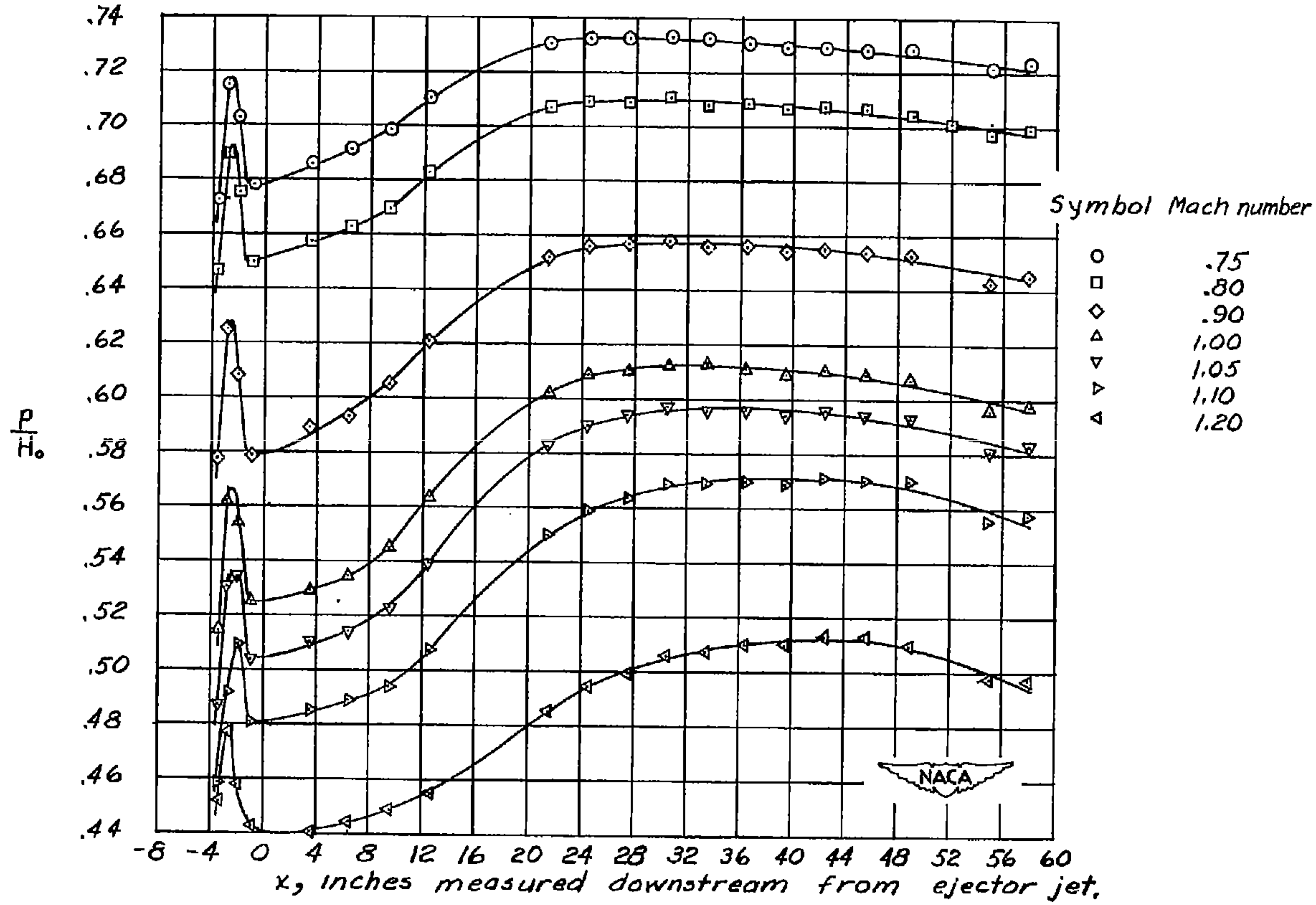
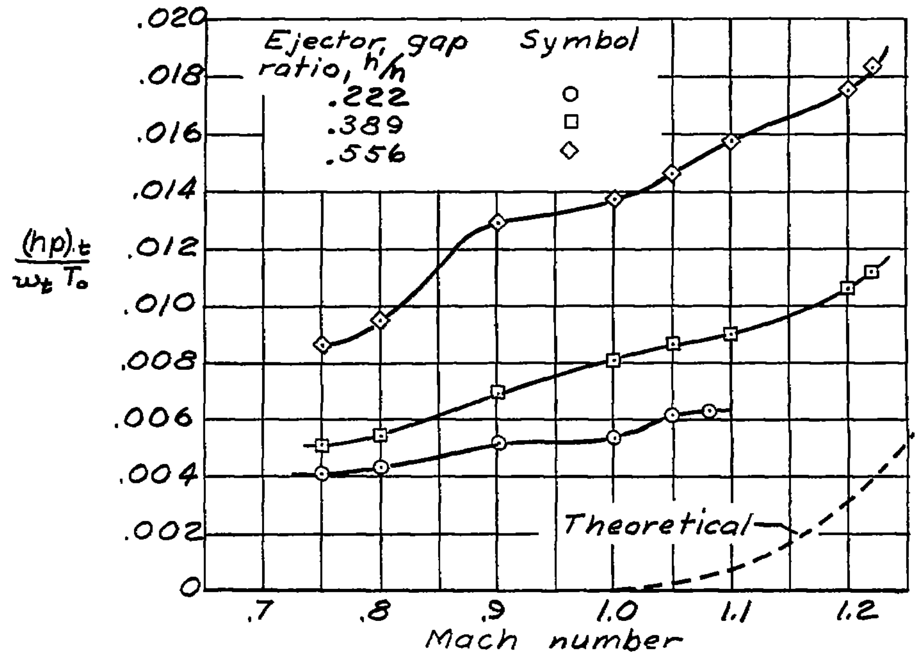
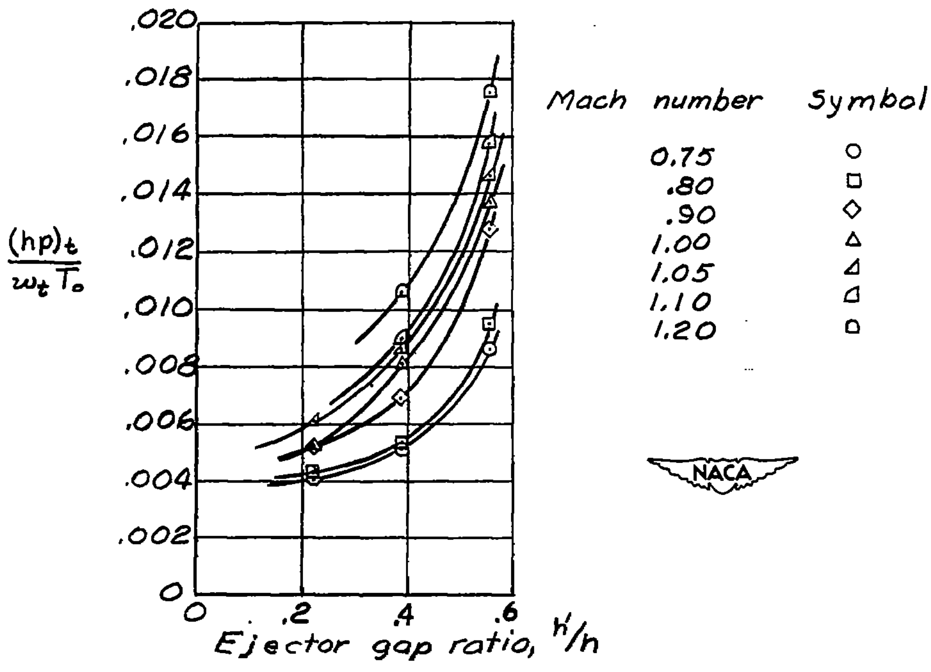


Figure 9.- Longitudinal static pressure distribution measured on the lower wall of the $\frac{l}{h}$ = 13.33 mixing tube at stations downstream of the ejector exit.



(a) Ejector gap ratio constant.



(b) Mach number constant.

Figure 10.- Variation of power with ejector gap ratio at several values of Mach number $\frac{l}{h} = 8$. See fig. 2(c).

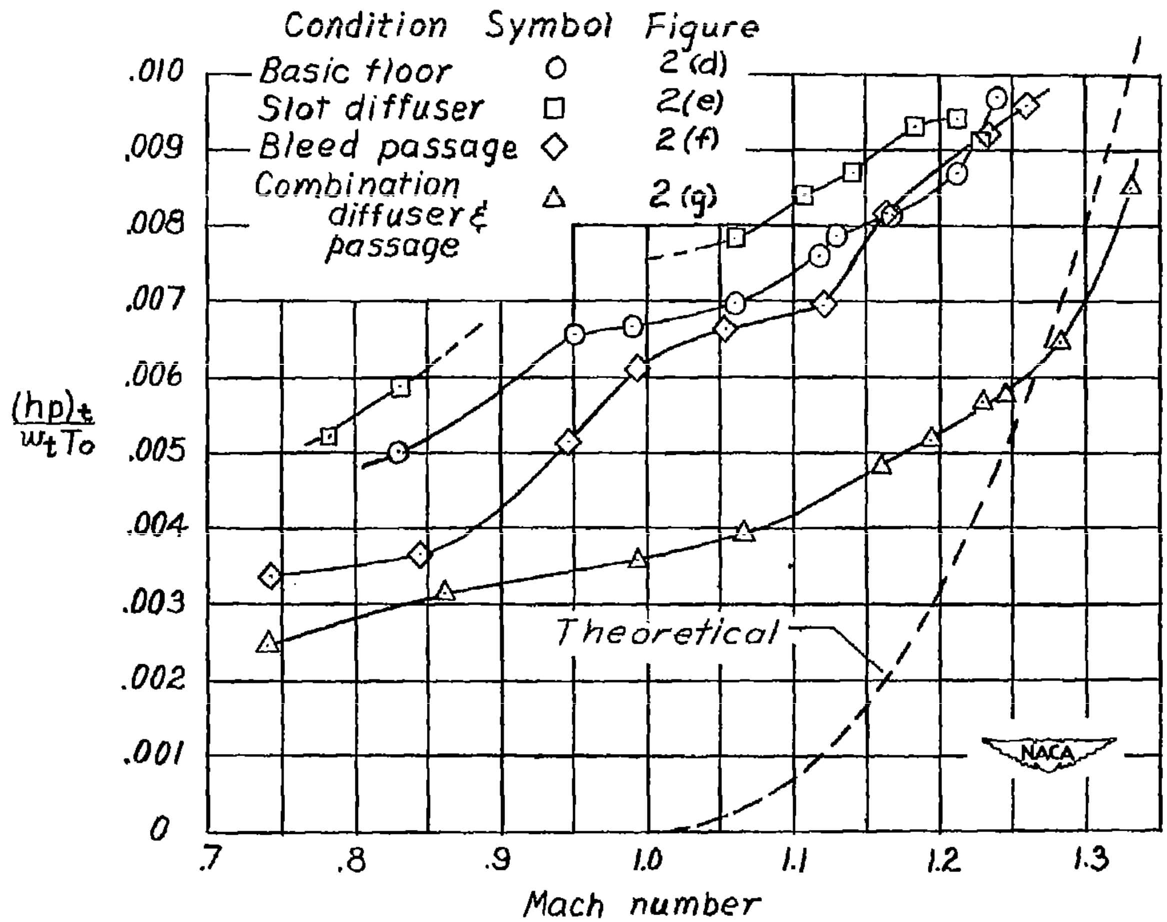


Figure 11.- Variation of power required with Mach number for several open-ejector configurations.

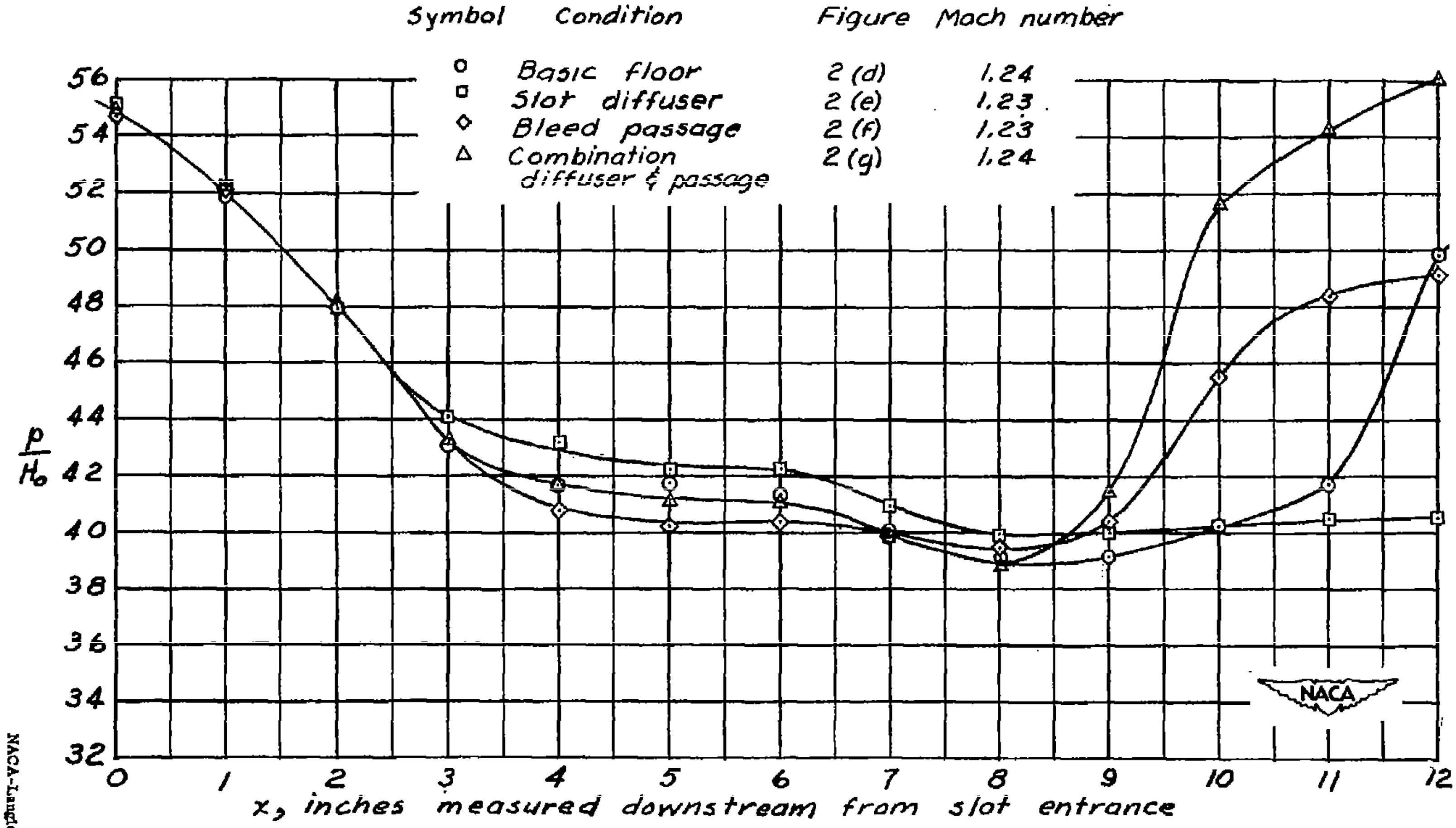


Figure 12.- Longitudinal static-pressure distribution for several open-ejector configurations.